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ABSTRACT

Many educators promote the goal of "scientific literacy for all" as the central organizing theme of their discipline. On the other hand, some critics of the goal are now becoming more vocal. One issue in particular concerns the charge that scientific literacy is a "vague, ill-defined" concept. Different meanings or interpretations for the goal could have significant impacts on its implementation and achievement. This interpretive synthesis of the literature on the concept of scientific literacy considers how science educators have historically defined and described scientific literacy, and ascertains whether or not fundamental differences in meanings and interpretations are really present. Among these findings are the elements comprising the concept of scientific literacy have nearly doubled since the term's introduction in 1952. The elements most commonly associated with scientific literacy include conceptual knowledge of the sciences, and the relationships between science and society, and science and technology. No two publications list exactly the same elements for scientific literacy, but there have been no new elements added to the accrued list since the introduction of the first national policy document for the goal in 1989. However, the reform documents that purport to define the term give it a definition that is many dozens of pages in length. It is suggested that shorter, more understandable definitions for the term might be useful. Alternatively, 'scientific literacy' has also taken on status as a slogan, and as such it may actually be beneficial not to define it too closely. (Contains 71 references and 9 figures.) (Author/YDS)

Science Educators' Views on the Goal of Scientific Literacy for All:

An Interpretive Review of the Literature

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Abstract

Many science educators promote the goal of "scientific literacy for all" as the central organizing theme of their discipline. On the other hand, some critics of the goal are now becoming more vocal. One issue in particular concerns the charge that scientific literacy is a "vague, ill-defined" concept. Different meanings or interpretations for the goal could have significant impacts on its implementation and achievement. This interpretive synthesis of the literature on the concept of scientific literacy considers how science educators have historically defined and described scientific literacy, and ascertains whether or not fundamental differences in meanings and interpretations are really present. Among the findings are the elements comprising the concept of scientific literacy have nearly doubled since the term's introduction in 1952. The elements most commonly associated with scientific literacy include conceptual knowledge of the sciences, and the relationships between science and society, and science and technology. No two publications list exactly the same elements for scientific literacy, but there have been no new elements added to the accrued list since the introduction of the first national policy document for the goal in 1989. However, the reform documents that purport to define the term give it a definition that is many dozens of pages in length. It is suggested that shorter, more understandable definitions for the term might be useful. Alternatively, 'scientific literacy' has also taken on status as a slogan, and as such it may actually be beneficial not to define it too closely.

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Science Educators' Views on the Goal of Scientific Literacy for All:

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Introduction

Many science educators in the United States (and elsewhere) currently promote the goal of "scientific literacy for all" as the central organizing theme of their discipline. However, the goal of scientific literacy for all is not without its critics. One issue in particular concerns whether or not a consensual definition for the term "scientific literacy" currently exists. Although the roots of the "scientific literacy" concept certainly extend back two centuries or more (Bybee, 1997; Chun, Oliver, Jackson, and Kemp, 1999; DeBoer, 1991; Hurd, 1987, 1990, 1998), the term itself apparently originated in the 1950s (Conant, 1952). Just a few years later, science educators realized that the term had taken on multitude of meanings (Carlton, 1963; Johnson, 1962; Koelsche and Morgan, 1964). Atkin and Helms (1993) assert that the broad goal of scientific literacy is actually a collection of many different aims or more narrow goals that have accumulated over time. In their view the meanings for "scientific literacy" have continually expanded rather than becoming more refined and focused. Matthews (1994) states "there is no one correct definition of science literacy; it is a matter of different conceptions proving their worth for the promotion of particular ends." In other words, one's definition may depend upon one's purpose at the moment.

Scientific literacy's most vocal critic, the physicist Morris Shamos has stated:

> there is no consensus on what 'scientific literacy' means or should mean. Instead, everyone involved with science education appears to have a vague, ill-defined notion of what it should mean, ranging from the simplistic view that any exposure to science contributes something to the state of mind called 'scientific literacy,' to the equally naive view that scientific literacy means being able to think like a scientist. (Shamos, 1995, p. 160)

However, Bybee (1997) counters asserting that scientific literacy has not been defined shows either an ignorance of the historical literature, or a particular dislike for the definitions that have been put forth. On the other hand, Laugksch (2000) contends that scientific literacy does have "different meanings and interpretations" due to a complex interaction between factors associated with the goal, such as different interest groups, conceptual definitions in the literature, nature of the concept, rationales for the goal, and ways of measuring it. So, despite an early realization that the concept had a number of meanings, and hundreds of publications concerning scientific literacy in the years that followed, nearly 50 years after its origin Laugksch (2000, p. 71) contends there is still "a view that scientific literacy is an ill-defined and diffuse concept." As Maienschein (1999) puts it, "'Scientific literacy' has become a buzz phrase to capture different things, a confusion that is useful at times because it allows people to think they agree when they really do not. Yet, hiding disagreements also keeps us from understanding how we might make things better."

If there is indeed a lack of consensus on the meaning of "scientific literacy," it logically follows there can be little agreement on how to work towards it and how to know when it has

been achieved. On the other hand, some might say that having a single definition for an educational goal such as scientific literacy is too limiting and may even be damaging in the long run. For example, a universal definition carries with it certain implications of uniform methods of implementation, assessment, etc. that does not respect individual or local differences (Heath, 1986). It may be that the ideal of "for all" when attached to "scientific literacy" necessitates a multitude of meanings (and rationales) for the goal.

Purpose and Research Questions

Bybee (1982, p. 2) stated, "Understanding the history of science education gives a perspective on present events. Having historical perspective does not make decisions easier, but it enables individuals to see consequences and alternatives which might otherwise be overlooked." Unfortunately, he found there is a "regrettable lacunae in the literature of science education" regarding historical research (Bybee, 1982, p. 1). Of the thousands of articles and dissertations he surveyed, less than 2% "were about the history of science education" (Bybee, 1982, p. 1). A few books taking a historical look at science education have been published since Bybee made these remarks (e.g., DeBoer, 1991), but my sense is the science education research literature still largely lacks historically-oriented publications. Thus, one purpose of this paper is to help contribute to the historical literature on science education in the hopes that it will have "a positive benefit to both the individual initiating the research and to the profession" (Bybee, 1982, p. 2).

The other purpose of this interpretive synthesis of the literature is to investigate how science educators have historically defined and described scientific literacy, and to ascertain whether or not fundamental differences in meanings and interpretations are (were) really present, and if so, what are some of the implications. Specific research questions include:

1) What are the current and historical "elements" of the scientific literacy concept? That is, what are the major types of knowledge, skills, attitudes, etc. that are said to result in or be displayed by a scientifically literate person?
2) Has the concept of scientific literacy changed significantly since its introduction?
3) Is scientific literacy still a "vague, ill-defined" concept, as Shamos (1995) alleges?
4) Do the elements of scientific literacy accrete over time, as Atkin and Helms (1993) assert?
5) Have recent national policy documents brought consensus to views of scientific literacy, at least among science educators, as Bybee (1997) suggests?

One question not addressed here is the question of why scientific literacy is promoted as a necessary or desirable state, i.e., the rationales for the goal. I address this question in another paper (Kemp, 2000).

Methods

Historical research can broadly be defined as "the process individuals use to identify significant ideas, events, persons and institutions of the past" (Bybee, 1982, p. 3). Facts alone have little meaning, so the researcher analyzes and interprets pertinent information in an attempt to establish "significant relationships about past phenomenon" (Bybee, 1982, p. 4). Perhaps the key words in the preceding sentences are "significant" and "pertinent." The sources included in this review include articles, books, and archived or microfiche documents dealing with the

concept of scientific literacy. If one types the key words "scientific literacy" into the ERIC database, more than 1000 references can be located. To limit the pool of potential documents to a more manageable number, I had to employ a number of criteria. First, there was my overarching purpose which was to locate documents that were *about* scientific literacy, i.e., not those that merely used the concept but those that explained, defined, described or otherwise explored the meaning for the term or goal. This reduced the number considerably. Second, as I was primarily interested in scientific literacy's history in the United States, I only considered English language documents, and only those that I considered to be readily available in the US. Thirdly, only those documents that are cited in other documents about scientific literacy are used (with the exception of some the latest ones). In other words, even if a document was about scientific literacy and was widely available, I did not consider it if it had not been cited elsewhere. And finally, I had to be able to gain access to the documents. For example, Bybee (1997), Laugksch (2000), and others cite the "Scientific literacy papers" from Oxford, UK, but I could not locate a copy of these "papers" and so they are not reviewed here.

One limitation of the study is I have not included sources that do not use the term "scientific literacy" or one of its morphs, but which may well have contributed to the development of the concept. For example, I did not use sources that refer to one particular aspect of scientific literacy, e.g., "intellectual independence" (Norris, 1997), nor those that might have spoken about "public understanding of science" or "science for all," unless they directly address "scientific literacy" as well. Even though these latter phrases are often viewed as a synonyms for "scientific literacy," I did not want to make the assumption that they are, in fact, talking about the same concept. For one thing, "scientific literacy" can be viewed as a product, whereas "science for all" can be viewed as the means of achieving that goal. Even if both are viewed as end states, I have reason to believe that they are not the same goal, and may actually be contradictory aims (Tippins, Nichols, and Kemp, 1999; Kemp, 2000).

To place the development of the scientific literacy concept in historical context, I found several sources to be quite helpful, including Bybee (1997), Cremin (1964), DeBoer (1991), Matthews (1994), Raizen (1991), Ravitch (1983), and Shamos (1995). Bybee's 1982 paper on "Historical research in science education" also guided my inquiry. The "elements" which comprise the concept of scientific literacy were derived by open coding the documents, followed by some axial coding, as described by Strauss and Corbin (1990).

Historical Meanings of "Scientific Literacy"

1952-1963: "Period of Legitimation"

Science educators at the time of W.W.II and immediately thereafter were especially interested in school science that students would find personally useful (Matthews, 1994). This "applied" or "practical" approach was in consonance with the precepts of the child-centered progressive education movement that pervaded all of education prior to the war (Cremin, 1964; Ravitch, 1983). It was at this time that the term "scientific literacy" was apparently first introduced by the President of Harvard University, James Bryant Conant.[1] Conant wrote a Foreword for *General Education in Science* (Cohen and Watson, 1952) in which he discussed the need for individuals to evaluate experts and their advice:

[1] Paul Hurd (1958) is often credited with coining the term "scientific literacy" (e.g., DeBoer, 1991; Laugksch, 2000; Roberts, 1983). However, as Bybee (1997) points out, Conant used the term as early as 1952.

> Such a person might be called an expert on judging experts. Within the field of his experience, he would understand the modern world; in short, he would be well educated in applied science though his factual knowledge of mechanical, electrical, or chemical engineering might be relatively slight. He would be able to communicate intelligently with men who were advancing science and applying it, at least within certain boundaries. The wider his experience, the greater would be his scientific literacy (Cohen and Watson, 1952, p. xiii, emphasis added).[2]

In Conant's view, then, scientific literacy is a matter of education and experience, and it results in the ability to "communicate intelligently" about scientific and technical matters. Conant was no doubt asked to write this Foreword because he was seen as a leader in the "general education" movement, and he saw the "scientific world view as a hallmark achievement of Western civilization" (quoted in Holton, 1998/99, p. 184).

In the 1950s, science education began to undergo reforms as the result of several contextual factors. For one thing, the educational system in general was undergoing an expansion as a result of the post-war "baby boom," resulting in more attention directed towards the schools (Ravitch, 1983). Criticisms against the progressive education approach were also mounting during the early part of the decade (Bestor, 1953; Lynd, 1953; Woodring, 1953). These critics urged a return to the teaching of the core knowledge of the basic subjects, such as English, history, math, and science (Ravitch, 1983). Some academics, scientists, and professional associations were especially concerned that progressive curricula did not prepare students well enough in math and science to provide the country with the number of scientists and engineers perceived necessary to stay competitive with the Soviets (Matthews, 1994; Raizen, 1991). Then, in 1957, the Russian satellite *Sputnik* was launched. Suddenly, the American public became highly conscious that science education in the United States was in need of reform. The idea of science education reform was discussed in many articles and reports, and occasionally in the public press.[3] In 1958, the term "scientific literacy" or its morphs ("science literacy," and "literate in science") appeared in at least 3 of these reports and articles in connection with the idea of reform.[4] The first was a panel report for the "America at Mid-Century Series" project, funded by the Rockefeller Brothers. It included a short section about the "crisis" in US science education, which the writers attributed to "our breath-taking movement into a new technological era" (p. 28). The writers noted the technological prowess of the Soviet Union did not 'cause' the crisis, but rather served as a "rude stimulus to awaken us to that reality" (p. 28). They called for better education of scientists, but cautioned:

> There is a danger of training scientists so narrowly in their specialties that they are unprepared to shoulder the moral and civic responsibilities which the modern world thrusts upon them. But just as we must insist that every scientist be broadly educated,

[2] It is not insignificant that Conant refers to "men" and not women; this chauvinistic view predominated at that time and is also evident in later discussions of scientific literacy. It might also be argued that by "men" Conant was actually referring to Caucasian males and not to people of other colors, even though general education was purportedly "for all."

[3] For example, there was an article in the *Saturday Review* in 1957—Bailey, H.S. (1957). How to be literate in a scientific age. *Saturday Review 40*, 13-15.

[4] I have identified only one source that makes any distinction between the terms "scientific literacy" and "science literacy." Maienschein (1999) suggests that "scientific literacy" refers to the scientific habits of mind needed by everyone, whereas "science literacy" refers to the scientific knowledge particular to experts. Maienschein, J. (1999). Commentary: To the future--Arguments for scientific literacy. *Science Communication 21*(1), 75-87.

> so we must see to it that every educated person be *literate in science*. In the short run this may contribute to our survival. In the long run it is essential to our integrity as a society. (p. 28, emphasis added)

However, the report did not go on to define the phrase "literate in science."

Even though he did not invent the term, Paul Hurd's (1958) use of the term "scientific literacy" is given credit for introducing the concept as a major theme for science education (Bybee, 1997, Hurd, 1998). In 1958, Hurd published "Science Literacy: Its Meaning for American Schools" in the October issue of Educational Leadership. Hurd (1958) noted, "science with its applications in technology has become the most characteristic feature of modern society" (p. 13). Americans are concerned, he declared, that their children be able to "cope with a society of expanding scientific and technological developments," as well as to "continue the accelerated momentum of science" (Hurd, 1958, p. 14). Therefore,

> More than a casual acquaintance with scientific forces and phenomena is essential for effective citizenship today. Science instruction can no longer be regarded as an intellectual luxury for the select few. If education is regarded as sharing of the experiences of the culture, then science must have a significant place in the modern curriculum from the first through the twelfth grade (Hurd, 1958, p. 13).

Thus, Hurd (1958) claimed "science literacy" was necessary for all individuals in the interests of our collective "social progress and economic security" (p. 52). However, Hurd never explicitly defines what he means by the term "scientific literacy" in his 1958 paper. By implication we can see it has something to do with developing an understanding of science as a method of theoretical inquiry, an appreciation for science as a human endeavor, and a preparation for rapid changes in our cultures and world due to advances in science and technology.

Hurd (1958) remarked that science education was being commented "upon by the President and debated in Congress" in the late 1950s. Opinions and money were also being contributed by businesses and industry. One such business was the Shell Chemical Corporation. Its president, Richard C. McCurdy, spoke about scientific literacy in ceremony at Cornell University honoring the Shell Merit Fellowship recipients. His speech was published in the November issue of *The Science Teacher* with the title, "Toward a Population Literate in Science." McCurdy said an understanding and appreciation of natural science would "help prepare the student to participate in human and civic affairs, whatever his calling may be" (1958, p. 366). McCurdy advocated that all students be taught science, especially at the secondary level. He quoted from the "Rockefeller Report" referenced above, and also from the physicist Frederick Seitz (1958). In discussing the "non-science" student, Seitz (1958, p. 15) said he would

> Place primary emphasis on a continuing course in general science at the secondary school level, which gives familiarity with the history and accomplishments of science and its relation to the matters of everyday life. This should be descriptive and inspirational, placing emphasis upon the cultural roots and the goals of science and the countless ways in which it affects our understanding of the world about us.

Seitz, however, did not actually use the term "science literacy," and the above quotes are as close as McCurdy comes to defining what he means by "literate in science."

Thus the term "scientific literacy" began as "a rallying symbol for an educational ideology" (Roberts, 1983). Roberts (1983) refers to this early period in scientific literacy's history as the "period of legitimation" (p. 25). The idea of scientific literacy in the 1950s and early 1960s included the premise that all students, not just those destined to become scientists and engineers,

should acquire some understanding of science. Although educators recognized that no one could know all the details of the various sciences, they were confident that by restructuring the curricula and instruction in science classes students could also gain an appreciation of science as an intellectual enterprise. The primary route for acquiring this understanding and appreciation of science was thought to be through letting students actually act like scientists by exploring and discovering in laboratory situations. However, none of these early users of the term (or its morphs) explicitly defined the concept. They discussed the need for scientifically literate citizens, and even described some characteristics of scientifically literate people, but none ever state, "the term scientific literacy means..." Thus, the term "scientific literacy" got off to a somewhat ambiguous start.

1963-1975: "Period of Serious Interpretation"

One of the most important factors leading to changes in science education in the 1950s was the involvement of the federal government in both collegiate and pre-collegiate education, largely through the auspices of the National Science Foundation (NSF). Prior to this time, the involvement of the US federal government in education was viewed with suspicion. The NSF was founded in 1950 for the support of basic research (Wolfe, 1957). Within a few years, however, the education of future scientists was added to the NSF's mission and NSF began funding institutes to update the content knowledge of college teachers (Raizen, 1991; Wolfe, 1957). In 1954, the Foundation initiated its first summer institute for high school teachers. By 1956, there were 27 of these institutes (at various colleges and universities) designed to provide teachers with advanced knowledge in a specific discipline, and in 1965 there were 449. In fact, by the late 1960s fully one-half of all secondary science and mathematics teachers had participated in some form of institute activity at some time in their career (Raizen, 1991).

Besides updating teachers' content knowledge, the institutes increasingly took on an additional function, namely, to train teachers in the use of curricular materials produced with NSF support (Raizen, 1991). The late 1950s and 1960s are often called the years of the "alphabet curricula" in science education because the various NSF-sponsored curriculum improvement projects were (and still are) usually referred to by their initials. The first of these projects, MIT's Physical Sciences Study Committee (or PSSC) was initiated in 1956--a year before *Sputnik*. Similar projects followed in chemistry, biology, and math within the next few years. By 1975, NSF had given funds to 28 science curriculum reform projects (Matthews, 1994). Most of the early projects followed the model of PSSC, which used a team of leading scientists, science teachers, and instructional media experts to develop curricular materials, including textbooks and lab activities (Raizen, 1991). This use of teams and the active participation of first-rate research scientists regarded as experts in their fields was a marked departure from the preparation of traditional textbooks by one or two authors (Raizen, 1991).

The ultimate goal of most of these new high school science and mathematics curricular materials was to develop the country's "scientific manpower" (Raizen, 1991). The science materials were strictly theoretically and discipline oriented, that is, very little space was devoted to practical and technological applications of science (Matthews, 1994).[5] In comparison to the courses of the 1950s, Trowbridge and Bybee (1990) said the alphabet curriculum materials had:

- less emphasis on social and personal applications of science and technology

[5] There were some exceptions to this rule, however. The philosophy of Harvard's Project Physics course, for example, was that physics is for everyone, not just specialists (Trowbridge and Bybee, 1996).

- more emphasis on abstractions, theory, and basic science--the structure of the scientific disciplines
- increased emphasis on discovery--the modes of inquiry used by scientists
- frequent use of quantitative techniques
- newer concepts in subject matter
- an upgrading of teacher competency in both subject matter and pedagogical skills
- well integrated and designed teaching aids to supplement the courses
- little emphasis on career awareness as a goal of science teaching
- a primary orientation toward college-bound students.

This approach contrasted sharply with the reforms proposed by the 1958 scientific literacy papers reviewed earlier, which called for science courses to make explicit the links between science, technology, and society. Science was said to be important to know not just for its own sake, but because Americans used its products (technology) every day, and it concerned important social issues, such as whether or not to use nuclear power. However, Robert Carleton (1963; see also in Koelsche and Morgan, 1964) found that the scientists and science educators he polled thought of scientific literacy as primarily meaning a great deal of content knowledge in a broad range of science fields. Certainly, very few spoke of the relationship between science and society. Thus, the idea of scientific literacy was present in the early 1960s, but the goal of preparing more and better scientists and engineers dominated the enterprise of science education.

Then in the mid-1960s, educational priorities shifted back towards the concern with social and personal goals. Largely as a result of the civil rights movement, new federal programs were initiated for minorities, children from low socio-economic backgrounds, children with disabilities, and non-native English speaking students. In this broader context, the concerns of science educators also shifted. Coupled with a genuine desire to help the "underprivileged," there now seemed to be a glut of scientists and engineers, reducing the perceived need for more efforts to train and recruit them (Raizen, 1991). Science educators now desired to expose all students to science, especially at the elementary and junior high levels, because they would find it useful in their lives. However, high school science was not compulsory in most states in the 1960s, so the NSF sponsored projects were primarily affecting only a minority of students at the secondary level who voluntarily took science. By the mid-1960s the NSF began to fund curriculum improvement projects aimed at the pre-secondary school population, including *The Science Curriculum Improvement Study* (SCIS), the *Elementary Science Study* (ESS), and *Science: A Process Approach* (Raizen, 1991). Although one of the goals of these projects was to recruit students for the optional secondary science courses, this purpose was supposed to be subordinate to the concern of teaching science to *all* students as part of their general education in elementary and junior high schools (Raizen, 1991). By the mid-1970s, about 50% of the nation's school districts were using any of the NSF funded science curricula, and about 30% of the districts were using them in elementary schools (Jackson, 1983; Weiss, 1978).

During this period of time, science educators who knew about the concept of scientific literacy recognized the term lacked a precise definition. For example, Carleton's (1963) respondents gave a number of different definitions for (or elements of) scientific literacy. In 1962, Philip G. Johnson had listed scientific literacy as one of "the goals of science education," but he also remarked that this term actually expressed a number of divergent goals. Soon there were a number of attempts to clarify and operationalize the concept, in what Roberts (1983) calls the "period of serious interpretation" (p. 26).

In one attempt to come up with a usable definition, Koelsche and Morgan (1964) took the "literacy" part of the term quite literally. Koelsche and Morgan published an "analysis of scientific information needed by persons living in the sixties to interpret and understand printed materials appearing in newspapers and magazines" (Koelsche and Morgan, 1964, p. 4). They analyzed the content of 22 daily newspapers and compiled a list of 175 principles and 693 vocabulary words that appeared during the 6-month study. Reflecting on their study, they derived the following "adequate" definition for scientific literary: "scientific literacy is a level of science education achieved by people when their backgrounds in science are such that they can understand, interpret, and interrelate scientific phenomena with facility, and form relevant and independent conclusions from information acquired through the media of mass communication" (Koelsche and Morgan, 1964, pp. 33-34).

Recognizing the diversity of goals included under the banner of scientific literacy, Milton Pella, George O'Hearn, and Calvin Gale (1966; see also Pella 1967) examined one hundred published works to determine what science educators meant by the term. The 6 referents used most frequently, in descending order, were:

- Interrelations between science and society
- Ethics of science
- Nature of science
- Conceptual knowledge
- Science and technology
- Science in the humanities

Ten years after introducing the term, Paul Hurd once again influenced the discussion of scientific literacy. In 1968, he wrote a statement of the characteristics of the scientifically literate person for the National Science Teachers Association (NSTA). An excerpt from the statement (taken from Kolb, 1969) is given in Figure 1. Basically, Hurd says a scientifically literate person understands and appreciates science as a way of knowing, understands the nature of science, appreciates the interaction of science and technology, understands the natural world, is aware of the influence mutual influences of science and society/culture, and appreciates the objectivity of science.

In 1969, Haven Kolb summarized the uncertainty of the meaning of "scientific literacy" for the teaching-learning situation:

> To some it means merely dissemination through the school population of miscellaneous ephemeral facts. To others it means inculcation of a spirit of inquiry. To still others, it requires abundant student experience with laboratory investigation--inquiry in action and not merely dry-runs or passive witnessing of colorful screen-shadows; and it may include appreciation of the work of scientists. To many the social relevance of science, and of the technology springing from it, is the only really important aspect. True scientific literacy, however, must be some combination of these.

In the early 1970s, NSTA identified scientific literacy as the most important goal of science education (DeBoer, 1991). NSTA's Board of Directors approved a position statement on "School Science Education for the 70's" that began with the words: "The major goal of science education is to develop scientifically literate and personally concerned individuals with a high competence for rational thought and action" (NSTA, 1971, p. 47). The historian of science education, George DeBoer (1991, p. 177) says:

> What was clearly evident in the NSTA's position statement were the themes of social relevance, student interest, the relationships between science and other areas of the curriculum, the interdependence of science and technology, and the human aspects of the scientific enterprise. What was abandoned was the idea that the structures of the science disciplines should be studied largely for their own sake. The goal of education was to teach those aspects of science that would help students understand the world around them and that would provide them with the tools for acquiring new science knowledge in the future.

Norman Smith (1974) defined scientific literacy as "an understanding of the events around us, the ability to verify the truth of claims made by lay persons and the popular media about science, and the ability to evaluate the relevance and importance of scientific developments and projects in relation to the needs of society" (quoted from DeBoer, 1991, p. 176). Also in 1974, Michael Agin published a conceptual framework for scientific literacy based on a review of the literature. Agin's framework included 6 categories: science and society, the ethics of science, the nature of science, the concepts of science, science and technology, and science and the humanities. A quick comparison reveals this framework is virtually identical to the 6 referents identified by Pella, O'Hearn, and Gale (1966) eight years earlier, perhaps suggesting that the concept of scientific literacy had somewhat stabilized by the end of the alphabet curricula period.

The U.S. economy began to suffer from periodic bouts with inflation and recession related to the war effort in Vietnam during the late 1960s and early 1970s (Raizen, 1991). At the same time, U.S. public school enrollment decreased leading to teacher surpluses. As a consequence, education budgets decreased, and "the willingness to try innovations, which characterized the educational expansion after World War II, gave way to the need for retrenchment" (Raizen, 1991, p. 22), i.e., a "back to the basics" movement. As if this were not enough, the NSF's budget for pre-college education programs began to dry up after Congressional criticism of their costly and seemingly never-ending nature (Raizen, 1991). One of NSF's curriculum improvement projects in particular created such turmoil that precollege teacher funding received almost no funding in 1976 (Raizen, 1991). This project, *Man: A Course of Study*, was controversial for two (albeit related) reasons. First, the subject matter was controversial because it involved human adaptation to the natural environment, a subject not well received by certain religious groups. And second, NSF not only paid to create the project, but also to publish and disseminate it, giving the impression the federal government was imposing its (controversial) values upon the schools (Raizen, 1991). *Man: A Course of Study* became the subject of several Congressional investigations and Executive branch panels, and the scrutiny soon brought all of NSF's education programs under fire, essentially bringing the development of alphabet curricula projects to a standstill (Raizen, 1991).

1975-1983: "Further Interpretation"

Lacking public and financial support for reform and improvement, US science education could be said to have entered a period of relative stasis from the mid-1970s to the early 1980s. However, two important developments in the concept of scientific literacy occurred. The first came in 1975 when Benjamin Shen subdivided scientific literacy into three broad categories:

- Practical science literacy, which means "the possession of the kind of scientific knowledge that can be used to help solve practical problems," especially those related to health and survival (Shen, 1975, p. 46).
- Civic science literacy, with the aim of enabling "the citizen to become more aware of science and science-related issues so that he ... [can] participate more fully in the democratic processes of an increasingly technological society" (Shen, 1975, p. 48).
- Cultural science literacy, which is about knowing "something about science as a major human achievement" (Shen, 1975, p. 49).

Shen also gave an overall definition for "science literacy": "an acquaintance with science, technology, and medicine, popularized to various degrees, on the part of the general public and special sectors of the public through information in the mass media and education in an out of schools" (Shen, 1975, pp. 45 - 46). Shen's article was important because "he describes a social orientation and contextual emphasis for the various topics elaborated by other authors. Shen's view also encompasses a continuum of global, national, and personal dimensions" (Bybee, 1997, p. 58).

In March 1977, Lawrence Gabel presented the results of his study of "Perceptions of scientific literacy" at the annual meeting of the National Association for Research in Science Teaching. He had developed a "theoretical definition" of scientific literacy from the literature and tested it on 350 scientists and non-scientists. His analysis of the data revealed seven dimensions of scientific literacy for high school graduates, including: scientific inquiry, maintaining current awareness, valuing methods of science, personal application of science, distinguishing between science and technology, utilizing factual knowledge, and mutual involvement of science and society (Gabel 1976, 1977).

Also during this period of time, a number of studies took stock in lessons learned from the alphabet curriculum projects. The most important of these studies include Helgeson, et al. (1977), Stake and Easley (1978), Weiss (1978), and Harms and Yager (1981). Their general conclusion seems to be that the curricular reforms were only partially successful in improving student achievement in school science or in retention of science knowledge and skills. Many science educators believe the new curricula were good in and of themselves, but that problems arose in implementation (Matthews, 1994). That is, the problem was not with the course materials, but with the teachers and other parts of the system of schooling in the US. For example, Stake and Easley's (1978) case studies of teachers found that although teachers had new course materials, they continued to teach in the same old way. In addition, school systems did not have enough money to provide lab assistants, buy equipment, or support teachers' professional development (Matthews, 1994). Thus, the main lesson learned was "the mere change of curriculum, without change of teacher education, assessment tasks, resources and support, is not going to have any dramatic effect on student engagement, interest and learning of science or of any other subject" (Matthews, 1994, p. 20).

1983-2000: Scientific Literacy's Golden Age

In the late 1970s and early 1980s, Americans became concerned by the emergence of Japan and other Asian countries as economic powerhouses. There was "a general belief that America's international economic competitiveness--and thus its industrial leadership--was on the wane" (Laugksch, 2000, p. 73). These fears became particularly acute following the publication of *A Nation at Risk* in 1983 (National Commission on Excellence in Education, 1983). The language

and conclusions of this report were stark, e.g., "the educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a nation and as a people." The report expressed a particular concern about high school students' lack of facility in science and mathematics. Within the same year, twenty bills were put before Congress to address this "crisis" in science education (Matthews, 1994). Before the decade was out, over 300 reports addressed the poor state of US education, many of them specifically discussing science education.

The reform of science education in the 1980s "was clearly linked to the idea of scientific literacy, and the literature on the subject increased substantially (Bybee, 1997, p. 59). Unfortunately, scientific literacy "also began to take on a symbolic value distinct from its past conceptual development because individuals used it in variety of ways" (Bybee, 1997, p. 59). Scientific literacy was discussed so much that it would be impossible to summarize all the literature in a few short pages, so I will concentrate on selected documents.

The Spring 1983 issue of *Dædalus* (Journal of the American Academy of Arts and Sciences) was devoted to the topic of scientific literacy. It was here that Jon D. Miller first presented a framework that he has used for over a decade in several studies in an attempt to measure scientific literacy (see Miller, 1997). Miller conceptualizes scientific literacy as having 3 dimensions: (1) "the ability of the individual to read about, comprehend, and express an opinion on scientific matters" (Miller, 1983, p. 30); (2) to be "learned" in science, i.e., to have "an understanding of the process or methods of science for testing our models of reality" (Miller, 1997, p. 124); and (3) having a broad "public understanding of public policy issues--what Benjamin Shen ... characterized as 'civic science literacy'" (Miller, 1983, p. 32).

In "Achieving Wider Scientific Literacy," A. B. Arons (1983) offered a list of a dozen attributes of a "person who has acquired scientific literacy" (p. 92). I have summarized his list of attributes in Figure 2. Arons (1983) says his list is "neither exhaustive nor prescriptive," but merely "illustrates some of the insights that I believe characterize scientific literacy and that I find most college undergraduates, given time and opportunity, and having the willingness to exert some intellectual effort, can encompass" (p. 94).

Most of the rest of the articles in the *Dædalus* issue do not explicitly define the term "scientific literacy," and about half do not even discuss it directly, but instead talk about aspects of science education reform. However, the last article, by Stephen R. Graubard, starts out with the bold assertion:

> Even the most casual examination of this issue of *Dædalus* will suggest that the term 'scientific literacy' lacks all precision, that there are no generally accepted criteria for determining what an individual needs to know to be called scientifically literate, or why it is vital (or even important) for great numbers of Americans to wish to achieve such literacy. Basic competence in science--another way of defining scientific literacy--is clearly an elusive concept, made all the more so by a fundamental ambiguity, even among educators, about the kinds of scientific knowledge and understanding that it is useful for ordinary citizens to command.

Graubard was the editor of *Dædalus*, so perhaps he was in a position to make such a statement. On the other hand, he was a historian, not a science educator, so some might question his conclusions on that basis.

In early 1989, the American Association for the Advancement of Science sent out announcement advertising a forum on scientific literacy. The announcement asked recipients "to

rank 15 components of scientific literacy, with regard to the abilities that should characterize the typical high school graduate" (Collins, 1989, p. 136). The list of components included "the abilities to pose a question that can be addressed by scientific methods, to give a scientific explanation of a natural process, to use appropriate methodology, to read and understand science as it is presented in a newspaper, to interpret graphs, to envision science as worth of pursuit even without immediate practical gains, to define terms accurately, to design an experiment that is a valid test of a hypothesis, to describe natural phenomena, to use science in personal decisionmaking [sic], and to locate information about science when needed (Collins, 1989, p. 136). Collins (1989, p. 137) points out that what is missing from this list and "from all of the attempts to define scientific literacy is an enthusiasm and excitement for knowledge about science."

There are two interesting aspects of the list of components of scientific literacy described by Collins (1989). First, the list seems very nearly de-contextualized, i.e., there is little reference to how a person could use scientific literacy or why it is a desirable goal. Although there is an implication of science encounters in daily life, there is no mention of science in society, the relationship of science and technology, or any connection between science and any other disciplines or enterprises.

The second aspect that is interesting is for the first time, the abilities to actually do science are included explicitly in a description of a scientifically literate person. While science skills have been implicit in earlier definitions, and certainly were a cornerstone for learning science in the alphabet curricula years, none of the earlier descriptions of scientific literacy or scientifically literate people contain words that state unequivocally that an individual should be able to do science on his/her own. Incidentally, both these aspects of the list are in contrast to the first publication by AAAS's Project 2061 which came out the same year as the forum (see hereafter).

Champagne and Lovitts's chapter, entitled "Scientific literacy: A concept in search of definition," declares:

> Scientific literacy is the catch phrase of the educational discourse of the 1980s. National reports from the educational, governmental, and private sectors call upon the nation's schools to improve school science education and, as one consequence, stem the decline of the American economy. Although the reports agree that a scientifically literate citizenry is important to the nation, all fail to describe (in a way that enables measurement) what it means to be scientifically literate. (p. 1)

They say further that the disagreement on a definition stems from different people answering the question, "'What does it mean to be scientifically literate?'" in three different ways: some describe "the behaviors of scientifically literate persons in a variety of contexts"; others discuss "the mental state of a scientifically literate person--[the] knowledge, skills, and dispositions" of a scientifically literate person; and yet others make "references to educational experiences that are assumed to produce a scientifically literate person" (Champagne and Lovitts, 1989, p. 1). Even within one of these categories there can be considerable debate. For example, concerning the "mental state" of a scientifically literate person,

> To some, being scientifically literate means the appropriate application of scientific knowledge and reasoning skills to solving problems and making decisions in one's personal, civic, and professional affairs. For others, being scientifically literate means the ability and inclination to continue learning about science lifelong. For still others, scientific literacy is often equated with being knowledgeable about science and having

certain intellectual skills, whether they are used or not (Champagne and Lovitts, 1989, p. 3).

They constructed a visual representation of their framework shown in Figure 2.

Champagne and Lovitts (1989) also say that what constitutes scientific literacy changes with time. Paul Hurd (1989) suggests that conceptions of scientific literacy in the 1980s are (were) "out of step with the realities of living, learning, and working in modern America and that existing science curricula are socially, culturally, and cognitively outdated" (Champagne and Lovitts, 1989, p. 8). He therefore "reconceptualizes" the goals of science education to recognize "the realities of living, learning, and working in a changing society" (Hurd, 1989, p. 15). Thus, he proposes the goals of science education, and presumably the dimensions of scientific (and technological) literacy, are "to develop the abilities to (1) solve problems encountered in the worldplace and in the conduct of personal life and civic responsibility, (b) communicate effectively, (c) work in groups, and (d) learn how to learn" (Hurd, 1989, p. 21).

In response to the perceived crisis in science education in the U.S. the American Association for the Advancement of Science (AAAS) organized several panels into the National Council on Science and Technology Education June 1985. The Council was entrusted with a program entitled "Project 2061." The Council's task was to define and describe ways to achieve widespread science literacy among American students.

The first publication of Project 2061 appeared in 1989. This publication, *Science for All Americans* (Rutherford and Ahlgren, 1990), establishes a conceptual base for the science (including math and technology) knowledge, skills, and habits of mind that all students should have acquired by the time they finish high school. *Science for All Americans* (hereafter, *SFAA*) consists of 12 chapters that can be grouped into 4 categories (Rutherford and Ahlgren, 1990, pp. ix-x):

- understandings of "the nature of science, mathematics, and technology--collectively, the scientific endeavor--as human enterprises."
- "basic knowledge about the world as currently seen from the perspective of science and mathematics and as shaped by technology."
- "understandings about some of the great episodes in the history of the scientific endeavor and about some crosscutting themes that can serve as tools for thinking about how the world works."
- "the habits of mind that are essential for scientific literacy."

SFAA uses a very broad conception of scientific literacy, and perhaps for the first time explicitly includes mathematics, technology, and the social sciences under that term. Even though *SFAA* has broadened the basis of scientific literacy, overall the amount of detail students are expected to retain is said to be less than the discipline-oriented curricula of the 1960s and '70s. Ideas and thinking skills are emphasized rather than specific terms and procedures. Traditional boundaries between subject-matter categories are softened and connections are emphasized. Math and technology concepts are intertwined with science concepts. *SFAA* also makes it very clear that scientific literacy is a goal for all students, not just the most capable. Even though *SFAA* stresses the need for life-long learning, its objectives stop at the twelfth grade, leaving one to speculate about the appropriate science learning goals for college students and other adults.

J. Preston Prather (1990) said that "entering the 1990s, the science education profession still [lacked] a clear, philosophically justified definition of its boldly acclaimed goal, 'scientific

literacy.'" For example, even though *SFAA* says it "is about scientific literacy" (pp. v), finding an explicit definition of that term in the report is not easy. However, the Preface (pp. ix), states:

> *Science for All Americans* is based on the belief that the scientifically literate person is one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes.

Later on, *SFAA* (p. x) says

> Scientific literacy--which encompasses mathematics and technology as well as the natural and social sciences--has many facets. These include being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes.

Perhaps the reason *SFAA* is not more explicit about a definition is the concept of science literacy has become something so broad it cannot be reduced down to one or two sentences. In fact, the later publication by Project 2061, *Benchmarks for Science Literacy* (AAAS, 1993, p. xi) says that *SFAA* is the definition of science literacy: "*SFAA* answers the question of what constitutes adult science literacy, recommending what all students should know and be able to do in science, mathematics, and technology by the time they graduate from high school." And yet, further on *Benchmarks* (p. 322) gives a much shorter definition for the term:

> Science Literacy. A literate person is an educated person, one having certain knowledge or competencies. But of course the rules keep changing with regard to precisely which knowledge and competencies define literacy--the ability to write one's name and read a simple prose passage long since having been replaced by more demanding requirements. In today's world, adult literacy has come to include knowledge and competencies associated with science, mathematics, and technology. Project 2061 has undertaken, in *SFAA*, to identify the knowledge and habits of mind that people need if they are to live interesting, responsible, and productive lives in a culture in which science, mathematics, and technology are central--that is, to describe what constitutes the substance of science literacy.
>
> People who are literate in science are not necessarily able to do science, mathematics, or engineering in a professional sense, any more than a music-literate person needs to be able to compose music or play an instrument. Such people are able, however, to use the habits of mind and knowledge of science, mathematics, and technology they have acquired to think about and make sense of many of the ideas, claims, and events that they encounter in everyday life. Accordingly, science literacy enhances the ability of a person to observe events perceptively, reflect on them thoughtfully, and comprehend explanations offered for them. In addition, those internal perceptions and reflections can provide the person with a basis for making decisions and taking action.

In response to national standards developed for mathematics in the 1980s (and perhaps feeling left out of the development of SFAA and Project 2061), in the early 1990s NSTA elected to look into defining and achieving standards for scientific literacy. It soon found that it could not undertake this complex task alone, and so it turned to the National Academy of Sciences for help (NRC, 1996). Their efforts resulted in the publication of the *National Science Education Standards* (NRC, 1996), which has "an explicit goal ... to establish high levels of scientific literacy in the United States" (p. 21). The *Standards* (NRC, 1996, p. 22) defines scientific literacy as

> the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities. In the *National Science Education Standards*, <u>the content standards define scientific literacy</u>. [Emphasis added.]
>
> Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.
>
> Individuals will display their scientific literacy in different ways, such as appropriately using technical terms, or applying scientific concepts and processes. And individuals often will have differences in literacy in different domains, such as more understanding of life-science concepts and words, and less understanding of physical-science concepts and words.
>
> Scientific literacy has different degrees and forms; it expands and deepens over a lifetime, not just during the years in school. But the attitudes and values established toward science in the early years will shape a person's development of scientific literacy as an adult.

Thus, despite this lengthy definition, the Standards (1996, p. 22) imply the definition is much longer by saying "the content standards define scientific literacy" (as I underlined above). The science content standards include:

- Science as Inquiry
- Physical Science
- Life Science
- Earth and Space Science
- Science and Technology
- Science in Personal and Social Perspectives
- History and Nature of Science

Each of these standards are divided up between grades K-4, 5-8, and 9-12, and each are several pages long. Therefore, it would be impractical for me to go into any further depth about their details here. However, I will point out that comparisons of the content in the *Standards* and

SFAA or Benchmarks reveal there is greater than 90% overlap (AAAS, 1997). One of the major differences, however, is that the *Standards* imply a scientifically literate person should be able to do science, whereas Project 2061 publications say it is enough to know about how science is done.

During the 1990s, several publications appeared that were somewhat critical of the goal of scientific literacy (e.g., Eisenhart, Finkel, and Marion, 1996; Jenkins 1990, 1992; Layton, 1991). The strongest critique has been delivered by Morris Shamos (1995) in *The Myth of Scientific Literacy*. Shamos claims the term "scientific literacy" is not well defined. He (Shamos 1995, p. 89) defines "'true' scientific literacy" as follows:

> At this level the individual actually knows something about the overall scientific enterprise. He or she is aware of some of the major conceptual schemes (the theories) that form the foundations of science, how they were arrived at, and why they are widely accepted, how science achieves order out of a random universe, and the role of experiment in science. This individual also appreciates the elements of scientific investigation, the importance of proper questioning, of analytical and deductive reasoning, of logical thought processes, and of reliance upon objective evidence.

Shamos, says (1995, p. 90) that "true scientific literacy, as defined here, is unlikely to be achieved in the foreseeable future," though he concedes "some important elements of it may be."

Shamos (1995) says that an individual obtains 'true' scientific literacy only by passing through two other levels of scientific literacy in sequence. The first is "cultural scientific literacy," by which he means the individual knows several hundred science-related terms and their definitions. Using this "lexicon," the individual can "recognize many of the science-based terms (the jargon) used by the media, which is generally their only exposure to science, ... but for the most part this is where their knowledge of science ends" (Shamos, 1995, p. 88). An individual can, however, attain "functional scientific literacy" by learning to "converse, read, and write coherently, using such science terms in perhaps a non-technical but nevertheless meaningful context. This means using the terms correctly ...[and] knowing what might be called 'some of the simple, everyday facts of nature'" (Shamos, 1995, p. 88). For Shamos, one of the key aspects of this level is a functionally literate person "should be able to engage in a meaningful discourse on most science articles that appear in the popular press" (Shamos, 1995, p. 89). Shamos (1995) estimates the number of Americans at this level as 30% or less of the public, and the number possessing "true" scientific literacy is only 5 to 6 percent. True scientific literacy for all, he concludes, is an unachievable goal and should be abandoned.

In *Achieving Scientific Literacy: From Purposes to Practices*, Rodger Bybee (1997) disputes Shamos' claims and promotes his vision of scientific literacy and the reforms needed to accomplish the goal. Bybee says that, contrary to what Shamos' or anyone else believes, "claiming that scientific literacy has not been defined makes for engaging rhetoric, but the assertion is wrong" (Bybee, 1997, p. 70). Bybee (1997) traces the history of the term and its definitions over time. He notes "in many cases, the issue of accepting and using the term *scientific literacy* boils down to personal attitudes--what individuals like or don't like--and that is what ultimately determines its acceptance or rejection. It is much easier to use the term as a slogan and claim that it is seldom defined" (Bybee, 1997, p. 70). Bybee (1997, p. 116) maintains that the *National Science Education Standards*, "specifically the Content Standards, combined with [his] framework for scientific literacy ... establishes a contemporary definition of scientific literacy that is clear, complete, and usable." Once again, the implication is the definition for

scientific literacy is not a single statement, but instead is dozens of pages long. Bybee's framework for scientific literacy is shown in Figure 3. He says "the framework ... presents scientific and technological literacy as a continuum in which an individual develops greater and more sophisticated understanding of science and technology" (Bybee, 1997, p. 84). As you can see in Figure 3, Bybee's framework has levels of scientific literacy ranging from illiteracy to nominal and functional scientific literacy, then to conceptual and procedural scientific literacy, and finally to multidimensional scientific literacy. Bybee (1997, p. 84) says "this framework functions as a taxonomy for extant programs and practices and as a guide for curriculum and instruction." A very important feature of Bybee's view is that it discounts the idea a person either is or is not scientifically literate; rather, everyone is scientifically literate to some extent.

More recently, Paul Hurd (1998) has once again entered the scientific literacy debate. Hurd (1998) says that science today is very different from a few decades ago, and so our view of what constitutes scientific literacy must keep up with the changes. He (Hurd, 1998, pp. 413-414) also gives his latest definition of a scientifically literate person in a long list of attributes (Figure 4). I have not (yet) made a detailed comparison of this new list with the list Hurd gave in 1968, but the main difference seems to be Hurd now puts less emphasis on science content knowledge and being able to think like a scientist. Even so, the new list is substantially longer than the old one, perhaps reflecting the growth of the sciences, and their applications, in the last 3 decades.

Although he acknowledges that they have included personal and social dimensions, Hurd (1998, p. 411) criticizes the *Standards* and *Benchmarks* for adhering to "the traditional mode of curriculum development," which he describes as simply updating "the subject matter of traditional disciplines" from time to time. Hurd (1998) says the idea of scientific disciplines should be abandoned in school science, as it has in real science. Instead, he promotes a "lived curriculum" which includes a number of "personal, social, and cognitive concepts that students need to acquire" (p. 412) regarding science and technology. (I will not list these concepts here).

From an analysis of the English language literature concerning scientific literacy, Laugksch (2000) concludes the concept is perceived to be "ill-defined and diffuse" (p. 71) because of a complex interplay of "different factors that influence interpretations of this concept." He divides the factors into 5 groups and constructs a conceptual framework depicting the dynamic nature of the concept (Figure 6). The factors Laugksch discusses include interest groups, conceptual definitions, nature of the concept, purposes, and ways of measuring scientific literacy. The reader may find Laugksch's discussion of conceptual definitions of interest since he does not limit discussion to publications influential in the U.S. as I do in this paper. However, Laugksch does not describe his own definition of scientific literacy based on his research. Instead, he categorizes other's definitions into 3 groups, "Learned," "Competent," and "Able to function minimally as consumers and citizens." The knowledge and abilities required by the first two groups are made in reference to the scientific enterprise, whereas the latter refers to knowledge and skills required to function in society. The "Learned" category specifies no involvement with society and appears "to operate in a social vacuum" (p. 84), while the third category requires the "individual to use science in performing a function in society" (p. 84). The "Competent" category requires some interaction with society. The implication is that there are different purposes or rationales for each category of scientific literacy in this scheme, and by extension, different definitions of scientific literacy are very likely motivated by different purposes of the various composers.

Discussion

The concept of scientific literacy is intimately bound up in the history of science education over the last half century. When conceived of as a goal for the discipline, its only rival is the goal for more and better scientists, or the "science pipeline" as it is sometimes called. In the 1950s and 1960s, the science pipeline goal dominated the discipline's research and practice, but by the early 1980s the tables had turned. The science pipeline goal has by no means disappeared, but it is not currently fashionable for a science educator to openly state that his or her main aim is to produce more and better scientists, engineers, etc. (unless they are strictly interested in post-12th grade students).

During scientific literacy's rise to dominance, the concept itself grew and changed. If one compares the explicit elements included under the banner of scientific literacy from the early 1950s to the late 1990s, it is easy to see that the number of elements has increased over time (Figures 7, 8, & 9). There are several other possible conclusions one might draw from such a comparison, including:

1. As Atkin and Helms (1993) observed, earlier elements comprising the concept of scientific literacy are not replaced by later elements. Rather, the list of properties included under the umbrella of scientific literacy has grown larger over time, at least up until the publication of *Science for All Americans*. On the surface, this accretion appears to be rather slow. Only 6 elements were added following the original introduction of the term in 1952 (which included 7 elements). However, within any given element, new dimensions were being added that do not appear in this crude analysis. For example, "Intellectual independence" originally included being able to evaluate expert advice. Later, it also took on the meaning of being able to make one's own decisions in a given scientific matter, and later still, being able to ask a scientific question, then find and evaluate information to answer that question.
2. The fact that new elements have not been added to the concept of scientific literacy since 1989 suggests that the concept has reached a plateau of sorts. Although *SFAA* and *Standards* do not include all the elements, they do include most of them, and these documents are similar to one another, suggesting that these national-scale efforts to pursue the goal of scientific literacy are bringing some consensus to the concept, as Bybee (1997) has suggested.
3. No two publications have exactly the same elements, except for Pella, et al. (1966) and Agin (1974)--both of which were based on reviews of the literature. Thus, within any given time period, individuals did not agree (and still do not agree) on exactly which elements are necessary and sufficient to define scientific literacy.
4. Conceptual knowledge is the only element in common across all publications. However, a close reading of the publications would reveal that although knowing something about science is always required for scientific literacy, it is not necessarily the most important element. Also, there is disagreement about whether this knowledge must refer to individual disciplines, or should be more interdisciplinary or contextual (see Hurd, 1998).
5. Besides conceptual knowledge, there are a few other elements that show up in most of the conceptions of scientific literacy, especially "science in society" and "science and technology." In fact, these two categories often overlap and might more properly be labeled "science, technology, and society." From 1963 on, the "Nature of Science" category also becomes fairly continuous.

6. Since the term "literacy" is included in "scientific literacy," one might suspect that reading and writing science and related abilities (speaking, listening, drawing, viewing) would always be at the heart of any conception of scientific literacy. However, a look at the three figures reveals this is not the case; "Science communication" shows up in about 2/3s of the publications reviewed here. It is often implied that a scientifically literate person will be able to read and write, but only explicit statements are included in this analysis.

The presence of all these variations in elements of scientific literacy has no doubt contributed to the impression that the concept is "vague," "ill-defined," and "diffuse." Even today when there are benchmarks and standards in place, this impression remains (Laugksch, 2000). Part of the problem may lie in a lack of historical perspective on the part of science educators (Bybee, 1997), which I have hopefully helped to address.

Perhaps another even more significant factor contributing to misunderstandings about the "definition" of the term "scientific literacy" is that it is currently dozens or even hundreds of pages long, if *Benchmarks* (AAAS, 1993) and the *Standards* (1996) are to be believed. One might argue that in fact science educators now have descriptions rather than definitions. A definition should be limited to "a statement of the meaning of a word or word group" (Merriam-Webster, Inc., 1995). Consider the term "human." Definitions for this term include (Merriam-Webster, Inc., 1995):

1. of, relating to, being, or characteristic of humans;
2. having human form or attributes;
3. any of a species of primate mammals comprising all living persons and their recent ancestors; also: Hominid.

These brief statements are definitions. On the other hand, descriptions of humans would include a list of facts such as humans have (usually) 2 arms, legs, and eyes, 5 digits per appendage, hair, etc., as well as narratives about how these parts work, how humans behave, and so forth. A description is necessarily more detailed and thorough than a definition. Pages and pages could be written to describe each human being, and even more pages would be needed to describe groups of human beings. Therefore, I think the *Standards* (NRC, 1996), *Benchmarks* (1993), and lists such as Hurd's (1998) should not be thought of as *definitions*, contrary to what Bybee (1997) and others say. Instead, these lengthy lists of attributes or characteristics are *descriptions* of a scientifically literate person. That does not mean they are not useful--indeed, descriptions are indispensable; however, they are not what one would looking for in a definition.

One thing that might help the situation is to divide these descriptions of scientific literacy into parts, such as science knowledge and understandings, science skills, science values, science appreciation and awareness, etc., and then define each one of them. Then rather than referring to the parts collectively as constituting scientific literacy, one could simply refer to the parts individually. After all, it seems to me a big part of the debate is one of emphasis. Most science educators do not disagree about which characteristics to include in a description of a scientifically literate person as much as they argue about which of those attributes are the most important and desirable.

Alternatively, one could come up with a simple definition of "scientific literacy" which is somehow all-encompassing.[6] Shiland (1998, p. 616) has recently proposed "scientific literacy is

[6] It is important to recognize that the importance of science in individuals' lives and society and general has changed over the years, being much more important now than formerly. Thus, it is only natural to expect that the definitions of what constitutes scientific literacy have changed over time, and they will continue to change as the roles of science

the ability to use (not invent) commonly accepted theories in science to predict, explain and understand the natural world." I think a statement such as this is what we need. Similarly, we might say "Scientific literacy is the ability to distinguish science from non-science, and good science from bad science;" or perhaps, "Scientific literacy is the ability to apply the values of science to one's life." If you look through the *Standards*, *Benchmarks*, or Hurd's (1998) list, I think you will find that most of the characteristics of a scientifically literate person will fit under either one of these short definitions. Either one of these two statements is a vastly superior definition than the lengthy narratives given by *Benchmarks* or *Standards*.

One significant problem of coming up with a short definition for scientific literacy (besides the fact that there is no real mechanism for doing so) is that people will disagree with one another about what "science" is. For example, in Shiland's definition, it is implicit that science depends on theory. I am sure there are many science educators (though fewer scientists) who would disagree with this view of science in its contemporary form. In regards to the other definitions I proposed, I am sure it would be next to impossible to get all science educators to agree to what constitutes "good science," much less "bad," or "non-" science, and what the "values" of science are and how to apply them would be similarly controversial.

Even if science educators could agree upon a short definition for 'scientific literacy,' it might not be a good thing. To paraphrase Heath (1986, p. 25), scientific literacy has different legitimate meanings for members of different groups, with a corresponding variety of acquisition modes, functions, and uses.[7] A single universal definition of scientific literacy is therefore not necessarily desirable because it cannot possibly be acceptable or applicable to all people. A single definition of SL implies uniform methods of instruction, standardized assessments, etc.— it would apply equally to everyone and not recognize individual differences in learning styles, aptitudes, or interests.

If the central, most fundamental goal of our discipline is not focused and agreeable to all stakeholders, it logically follows we will have difficulty specifying what students need to learn, how they need to be taught and assessed, and in what directions our research should be headed in science education. So, why not abandon the term "scientific literacy" all together? One reason is its widespread usage and long history make it hard to ignore or relinquish. Science educators have devoted (and are still devoting) a lot of time, energy, and money towards the goal of scientific literacy. Another reason is the term "scientific literacy" has "an intuitive appeal and

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and technology continue to evolve. Therefore, a universal definition of scientific literacy would have to be a statement describing how a person has to keep up with and be able to use the science of their time. It would not be a statement of exactly what science knowledge, skills, or understandings a person should have, because such a statement would be too limited in the scope of time. However, statements of value are more long-lasting. It is also important to have a definition or definitions of scientific literacy that describe how people actually use or could use their science knowledge, skills, understandings, and dispositions in their actual lives, as opposed to the academically oriented statements we now have. No matter how science literacy is defined, there remains the questions of whether this is a useful concept, and is it a useful thing that all Americans need.

[7] Heath (1986) says of general literacy that "the concept ... covers a multiplicity of meanings, and definitions of literacy carry implicit but generally unrecognized views of its functions (what literacy can do for individuals) and its uses (what individuals can do with literacy skills)" (p. 15). It appears that the same may be said of scientific literacy, i.e., that the definitions of scientific literacy differ in the relationship they bear to the purposes and goals of science (and technology) in the lives of individuals.

convincing ring of legitimacy" (Prather, 1990). People outside the field of science education, including the general public, especially recognize the "literacy" part of the term and it connotes a socially desirable state. "Literacy" is viewed as a broad and abstract term that is an appropriate goal of education (Eisenhart, Finkel, and Marion, 1996). Bybee (1997, p. 150) says

> The good news is that the broad and abstract nature of the goal--scientific literacy--allows widespread agreement and a unifying idea for diverse groups within the science education community. For instance, science teachers, administrators, parents, curriculum developers, teacher educators, scientists, and policy makers can all support the idea of achieving scientific literacy. The bad news is that these diverse groups within the science education community have different perspectives on what scientific literacy is and how to achieve it.

He suggests that while it is true the term's definition has not always been clear, today there is much more agreement than disagreement about what constitutes a definition of scientific literacy. Bybee (1997) further concludes the *National Science Education Standards* (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993) have brought much more harmony and guidance to the process of defining and working toward scientific literacy, and my analysis suggests that Bybee is correct in this regard.

Conclusions

One change in science education since the goal of scientific literacy was introduced is that science educators promoting the goal are more politically savvy than those of an earlier generation. One lesson, in particular, that science educators seemed to have learned from the NSF projects of the late 1950s and 1960s is that the federal government can be generous with funding under the right conditions, specifically when there is a perceived threat to national interests. In the 1950s the threat was primarily related to security, in the 1980s it was economics. Currently, the threat that continues to sustain reform efforts seems to be one of national pride; Americans are ashamed by their poor standing in results of tests of international achievement. Whether or not a true crisis exists or has existed is not the question here; rather, I am pointing out that science educators are now much better prepared to deal with such a perceived problem.[8] On the other hand, another lesson science educators should have learned is that the federal resources are also subject to withdrawal if results are not demonstrable or sufficient to justify the expenditures. The alphabet curricula era drew to a close when Congress criticized their costly and seemingly never-ending nature (Raizen, 1991). The lackluster showing of US high school

[8] Science educators are also much more willing to accept support from the federal government then they were 50 years ago. In fact, it is now difficult to imagine reform in science education without such support. I think it is fair to say nowadays science educators do not turn to the federal government (or state governments for that matter) reluctantly, but actively and eagerly. Perhaps related to the previous trend, science educators now exhibit a much greater acceptance of national standards and benchmarks for scientific literacy than would have been conceivable in the 1950s. This acceptance is not limited to science educators, but extends to the public, administrators, policy-makers, etc. Establishing national curricula remains a controversial subject, but with the foundations laid by national standards and benchmarks, and given our international competitiveness with countries that do have national curricula, it is not too difficult to predict that such programs will soon be proposed and even accepted, at least as some level (elementary, middle, high school?).

students on the Third International Mathematics and Science Study (U.S. National Research Center, 1996) should give us pause to consider if we are headed in the right direction.

I have shown that the goal of scientific literacy has had a long and sometimes contentious history, and that even today there is no final consensus on what constitutes "scientific literacy." Nevertheless, I hope that consideration of the historical perspective I have presented here will help science educators make decisions about future directions for this important, but elusive, goal.

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Figure 1: Hurd's (1968) statement for the NSTA.

THE SCIENTIFICALLY LITERATE PERSON

A statement of goals for an education in the sciences should describe what we mean by a scientifically literate person living in modern times. This person is the end product, as we see him, of ten to fifteen years of science education, beginning with kindergarten. Here are some of the ways by which we can identify this person:

- He has faith in the logical processes of science and uses its modes of inquiry, but at the same time recognizes both their limitations and the situations for which they are peculiarly appropriate.
- He enjoys science for the intellectual stimulus it provides, for the beauty of its explanations, the pleasure that comes from knowing, and the excitement stemming from discovery.
- He has more than a common sense understanding of the natural world.
- He appreciates the interaction of science and technology, recognizing that each reflects as well as stimulates the course of social and economic development, but he is aware that science and technology do not progress at equal rates.
- He is in intellectual possession of some of the major concepts, laws, and theories of several sciences.
- He understands that science is one but not the only way of viewing natural phenomena and that even among the sciences there are rival points of view.
- He appreciates that knowledge is generated by people with a compelling desire to understand the natural world.
- He recognizes that knowledge in science grows, possibly without limit, and that the knowledge of one generation 'engulfs, upsets, and complements all knowledge of the natural world before.'
- He appreciates the essential lag between frontier research and the popular understanding of new achievements and the importance of narrowing the gap.
- He recognizes that the meaning of science depends as much on its inquiry process as on its conceptual patterns and theories.
- He understands the role of the scientific enterprise in society and appreciates the cultural conditions under which it thrives.
- He recognizes the universality of science; it has no national, cultural, or ethnic boundaries.

Figure 2. Champagne and Lovitts (1989) Conceptual Framework for Scientific Literacy.

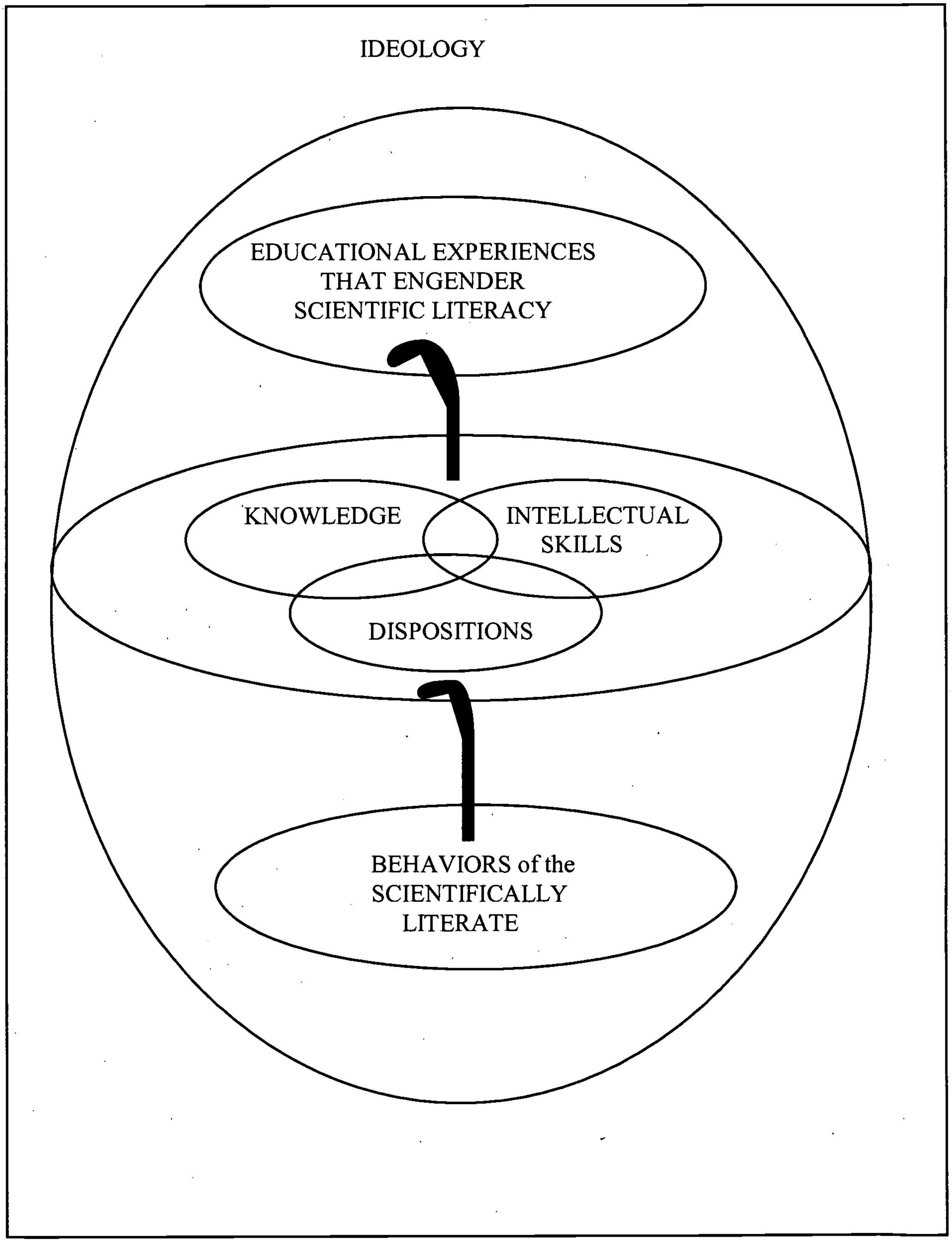

Figure 3: Arons (1983) list of the attributes of a scientifically literate person.

The scientifically literate person should:

1. Recognize that scientific concepts ... are invented or created by acts of human intelligence and imagination ...

2. Recognize that ... terms require careful operational definition ...; to comprehend ... that a scientific concept involves an idea first and a name afterward, and that understanding does not reside in the technical terms themselves.

3. Comprehend the distinction between observation and inference ...

4. Distinguish between [serendipity] ... and the deliberate strategy of forming and testing hypotheses.

5. Understand the meaning of the word 'theory' in the scientific domain, and to have some sense ... of how theories are [used] ...

6. Recognize when questions such as 'How do we know ...? Why do we believe ...? What is the evidence for ...?' have been addressed, answered, and understood, and when something is being taken on faith.

7. Understand ... the [tentativeness] ... of scientific concepts and theories ...

8. Comprehend the limitations inherent in scientific inquiry ...

9. Develop enough basic knowledge and understanding in some area (or areas) of interest to follow intelligent reading and subsequent learning without formal instruction.

10. Be aware of at least a few specific instances in which scientific knowledge has had direct impact on intellectual history and on one's own view of the nature of the universe and of the human condition within it.

11. Be aware of at least a few specific instances of interaction between science and society on moral, ethical, and sociological planes.

12. Be aware of very close analogies between certain modes of thought in natural science and in other disciplines ...

Figure 4. Bybee's (1997) Framework for Scientific Literacy (paraphrased from pp. 82-85)

Illiteracy
A person who is scientifically and technologically illiterate cannot understand questions about science, or locate them within the domain of science or technology. This state may be due to age, stage of development, or developmental disabilities.

Nominal Scientific and Technological Literacy
In *nominal* literacy, the individual associates names with a general area of science and technology. However, the association may represent a misconception, naive theory, or inaccurate concept. The relationship between science and technology terms and acceptable definitions is small and insignificant. At best, students demonstrate only a token understanding of science concepts, one that bears little or no relationship to real understanding.

Functional Scientific or Technological Literacy
Individuals demonstrating *functional* level of literacy respond adequately and appropriately to vocabulary associated with science and technology. They meet minimum standards of literacy as it is usually understood; that is, they can read and write passages with simple scientific and technological vocabulary. Individuals may also associate vocabulary with larger conceptual schemes--for example, that genetics is associated with variation within a species and variation is associated with evolution--but have a token understanding of these associations.

Conceptual and Procedural Literacy
Conceptual and *procedural* literacy occurs when individuals demonstrate an understanding of both the parts and the whole of science and technology as disciplines. The individual can identify the way the parts from a whole vis × vis major conceptual schemes, and the way new explanations and inventions develop vis × vis the process of science and technology. At this level, individuals understand the structure of disciplines and the procedures for developing new knowledge and techniques.

Multidimensional Literacy
Multidimensional literacy consists of understanding the essential conceptual structures of science and technology as well as the features that make that understanding more complete, for example, the history and nature of science. In addition, individuals at this level understand the relationship of disciplines to the whole of science and technology and to society.

Figure 5: Hurd's (1998) list of what a scientifically literate person should do:

- Distinguishes experts from the uninformed.
- Distinguishes theory from dogma, and data from myth and folklore.
- Recognizes that almost every fact of one's life has been influenced in one way or another by science/technology.
- Knows that science in social contexts often has dimensions in political, judicial, ethical, and sometimes moral interpretations.
- Senses the ways in which scientific research is done and how the findings are validated.
- Uses science knowledge where appropriate in making life and social decisions, forming judgments, resolving problems, and taking action.
- Distinguishes science from pseudo-science such as astrology, quackery, the occult, and superstition.
- Recognizes the cumulative nature of science as an "endless frontier."
- Recognizes scientific researchers as *producers* of knowledge and citizens as *users* of science knowledge.
- Recognizes gaps, risks, limits, and probabilities in making decisions involving a knowledge of science or technology.
- Knows how to analyze and process information to generate knowledge that extends beyond facts.
- Recognizes that science concepts, laws, and theories are not rigid but essentially have an organic quality; they grow and develop; what is taught today may not have the same meaning tomorrow.
- Knows that science problems in personal and social contexts may have more than one "right" answer, especially problems that involve ethical, judicial, and political actions.
- Recognizes when a cause and effect relationship cannot be drawn. Understands the importance of research for its own sake as a product of a scientist's curiosity.
- Recognizes that our global economy is largely influenced by advancements in science and technology.
- Recognizes when cultural, ethical, and moral issues are involved in resolving science-social problems
- Recognizes when one does not have enough data to make a rational decision or form a reliable judgment.
- Distinguishes evidence from propaganda, fact from fiction, sense from nonsense, and knowledge from opinion.
- Views science-social and personal-civic problems as requiring a synthesis of knowledge from different fields including natural and social sciences.
- Recognizes there is much not known in a science field and that the most significant discovery may be announced tomorrow.
- Recognizes that scientific literacy is a process of acquiring, analyzing, synthesizing, coding, evaluating, and utilizing achievements in science and technology in human and social contexts.
- Recognizes that symbiotic relationships between science and technology and between science, technology, and human affairs.
- Recognizes the everyday reality of ways in which science and technology serve human adaptive capacities, and enriches one's capital.
- Recognizes that science-social problems are generally resolved by collaborative rather than individual action.
- Recognizes that the immediate solution of a science-social problem may create a related problem later.
- Recognizes that short- and long-term solutions to a problem may not have the same answer.

Figure 6: Laugksch's (2000) "conceptual overview of scientific literacy"

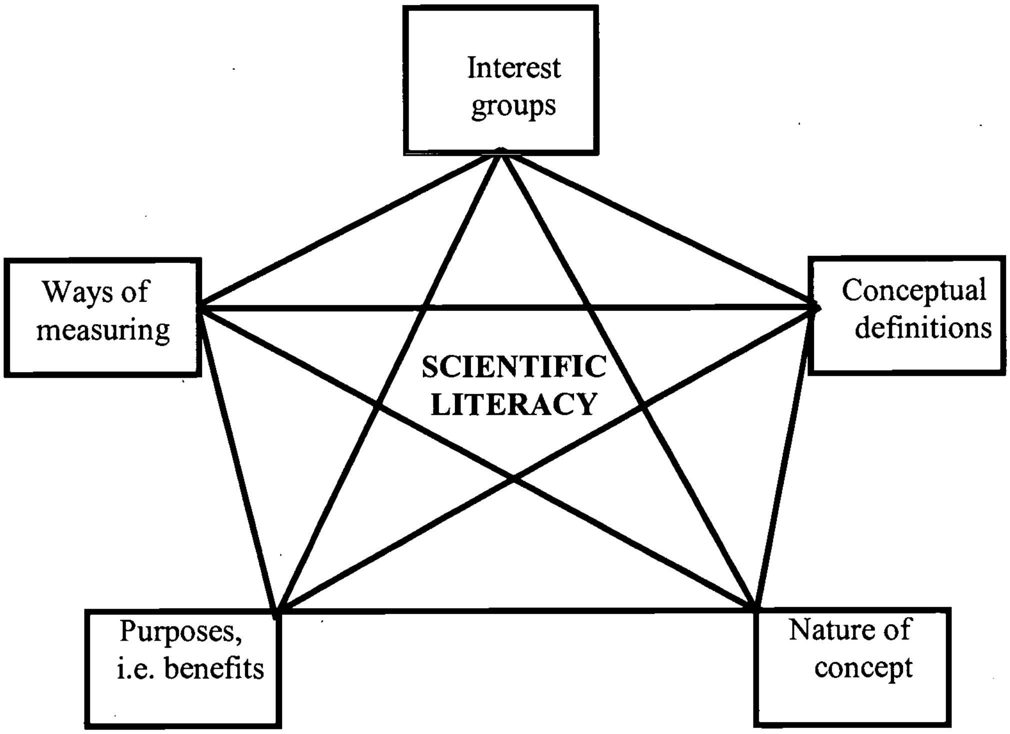

Figure 7: A comparison of the elements of scientific literacy 1952-1963.

Elements of Scientific Literacy	Conant 1952	Rockefeller 1958	Hurd 1958	McCurdy/Seitz 1958	Carleton 1963
Intellectual independence [a]	X				
Science communication [b]	X	X	X		X
Science and society [c]	X	X	X		
Conceptual knowledge [d]	X	X	X	X	X
Science and technology [e]	X		X		
Science in everyday life [f]	X			X	
Science appreciation [g]	X		X	X	
Ethics of science [h]		X			
Nature of science [i]			X		X
History of science [j]				X	

[a]"Intellectual independence" includes such things as being able to find out information and make a personal decision about an issue involving science, being able to evaluate "expert" advice, and the ability to continue to learn science after formal schooling ends.
[b] "Science communication" refers to the abilities required to both interpret science communications (e.g., reading, listening, viewing) and to encode such communications (e.g., writing, speaking, drawing), either with non-scientists or science specialists.
[c] "Science and society" includes understandings of the relationships of science and society, civics (democracy), culture, national security, and economics, as well as some understandings of how science is controlled/influenced by society.
[d] "Conceptual knowledge" refers to knowledge (facts and understandings) about the various science disciplines. All the documents shown here conceive of conceptual knowledge broadly, i.e., it should include some knowledge from an array of science disciplines, not just one or two.
[e] "Science and technology" refers to the interrelations between these two enterprises.
[f] "Science in everyday life" implies normal encounters with science and its products (technology), including those that help someone to be economically productive. It also includes statements such as "understand the modern world."
[g] "Science appreciation" implies a number of things, including support of basic and applied science, appreciation of science as a way of knowing and as a significant human achievement/endeavor, and intellectual stimulus/satisfaction derived from using science to answer one's own questions.
[h]"Ethics of science" includes knowing about and being about to apply the values of science, such as objectivity and logic, as well as the "moral and civic responsibilities" of science and scientists.
i "Nature of science" includes understanding such things as hypothesis testing (variables, controls), the reliance on testable evidence to make decisions, the tentative nature of scientific findings, and the self-correcting nature of the scientific enterprise.
[j]"History of science" means some "familiarity with the ... accomplishments of science" and scientists, but not necessarily a deep or detailed knowledge of science's history.

Figure 8. Elements of scientific literacy 1964-1982 compared to 1958-1963. For an explanation of all elements except the last, refer to Figure 7.

Elements of Scientific Literacy	1958-1963	Koelsche & Morgan 1964	Pella, et al. 1966	Hurd 1968	NSTA 1971	Agin 1974	Shen 1975	Gabel 1977
Intellectual independence	X	X			X			X
Science communication	X	X					X	
Science and society	X	X	X	X	X	X	X	X
Conceptual knowledge	X	X	X	X	X	X	X	X
Science and technology	X		X	X	X	X	X	X
Science in everyday life	X	X			X		X	X
Ethics of science	X		X			X		
Nature of science	X		X	X		X		X
History of science	X							
Science appreciation/support	X			X			X	X
Science in the humanities[k]			X		X	X		

[k] "Science in the humanities" refers to the relation of science to other disciplines in the curriculum, and the mutual influences that science and other disciplines might have had on one another.

Figure 9. Elements of scientific literacy 1983-1998 compared to 1952-1982. For descriptions of all but the last 2 elements, see Figure 7.

Elements of Scientific Literacy	1958-1982	Miller 1983	Arons 1983	AAAS (Collins) 1989	SFAA 1989	Shamos's "True" 1995	Standards 1996	Hurd 1998
Intellectual independence	X	X	X	X	X	X	X	X
Science communication	X	X	X	X	Implied	X	X	X
Science and society	X	X	X		X	X	X	X
Conceptual knowledge	X	X	X	X	X	X	X	X
Science and technology	X				X	X	X	X
Science in everyday life	X		X	X	X	X	X	X
Ethics of science	X		X		X		X	X
Nature of science	X	X	X	X	X	X	X	X
History of science	X		X		X	X	X	
Science appreciation/support	X		X	X	X	X	X	
Science in the humanities	X		X					
Science skills[L]				X			X	
Science and mathematics[m]					X	X	X	

[L]"Science skills" means actually being able to do science, as opposed to just recognizing or knowing about it. Although it has sometimes been implied, especially in regards to being able to think like a scientist, it is here made explicit for the first time.
[m]The connection between "Science and mathematics" is made explicit in SFAA, whereas it had been merely assumed in earlier conceptions of scientific literacy.

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